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Economic Dispatch of Multiple Energy Storage Systems Under Different Characteristics

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Abstract

This paper presents economic dispatch of the grid-connected microgrid that contains multiple energy storage systems as its only controllable distributed energy resources. Daily control schedules of distributed energy resources are achieved by solving the economic dispatch problem. The main objective of economic dispatch is maximizing the profit from the power trade with the grid. The economic dispatch problem presented in this paper considers the different characteristics of energy storage systems. Each energy storage system has its unique characteristics such as the charge/discharge efficiency and capacity fade rate. The result of the multi-objective problem shows that the energy storage system with the highest efficiency and the lowest capacity fade rate is controlled more frequently than the others. The Pareto optimal set of the resulting control schedules is presented.

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Keywords: Economic Dispatch; Energy Storage System; Efficiency; Capacity Fade; Pareto Optimal.

1. Introduction

An energy storage system (ESS) is a system that can store energy to satisfy needs of the operator. It can charge or discharge a specific amount of energy during a specific period. The well-known usage of an ESS is power shifting, which enables to decrease the net power usage of a specific time period by increasing the one of the other [1].

A microgrid is a local electrical grid that manages electrical resources within its electrical boundary [2]. It contains various distributed energy resources (DERs) such as a PV, wind turbine, diesel power generator, and ESS.

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Each DER generates or consumes power following its own physical and electrical limitations. Economic dispatch (ED) aims to schedule DER operations under considerations about the cost optimization and system restrictions [3].

In this paper, the ED problem is generated and solved for the grid-connected microgrid. A microgrid connected to the grid could buy or sell power to the grid. Unit power trading price is predefined daily for each hour of the day. The microgrid operator could schedule DER operations as a result of the ED problem. It helps the microgrid to minimize the operation cost such as the grid power usage and the power generation cost.

The grid-connected microgrid presented in this paper contains multiples ESSs as its only controllable DERs. Each ESS has its unique characteristics such as the power capacity, energy capacity, charge efficiency, discharge efficiency, and capacity fade rate. Characteristics of ESSs, especially the efficiency and capacity fade rate, are applied to the ED problem to provide precise control schedules.

ED problems of diesel power generators could be solved analytically by applying Lagrange multipliers [4]. However, the existence of an ESS makes the problem complicated because of its time dependency [5]. The amount of energy stored in the ESS should always be maintained within its minimum and maximum capacity values. Several studies focused on economic dispatch or optimal scheduling of energy storage systems. ED problems are solved using various optimization techniques such as linear programming [6,7], evolutionary algorithm [8], and dynamic programming [9]. Riffonneau et al. [9] and Choi et al. [10] applied state dependent characteristics of ESS efficiencies to the optimization. The capacity fade of an ESS is also considered in some studies [9,11] to provide broader information for the ESS condition.

This paper focuses on the grid-connected microgrid that contains multiple energy storage systems. The ESS with a low efficiency or a high capacity fade rate is expected to be not operated frequently because of the optimized control. Furthermore, the prediction for the capacity change would make the ESS to be controlled within its safe capacity range.

2. Energy Storage System

An ESS can store electrical energy by converting it to different types of energy such as mechanical, electrical, and electrochemical one [12]. The most common type of ESS is an electrochemical system, which is known as a battery. A battery stores electrical energy as a form of chemical energy by changing its chemical compositions.

There is an energy loss during energy conversion and storing processes of ESSs. This internal energy loss is represented as charge and discharge efficiencies. To minimize the energy loss and corresponding cost, the efficiency of an ESS has to affect its operation schedule as the result of ED.

In addition to its efficiency, the aging of an ESS is a major issue that should be concerned prior to applying it to the microgrid. It could permanently decrease not only the efficiency but also the maximum energy capacity.

Decreasing of the maximum energy capacity, which is known as a capacity fade, is a well-known phenomenon that happens during its lifetime of an ESS, especially for a battery based one [13]. The capacity fade of any type of ESS is a serious problem because it makes the ESS condition differ from what it has to be. If the operator tries to use the ESS with its initial maximum capacity limitation, the ESS could not serve it and, even worth, it can cause safety problems. Applying the capacity fade rate to the ED problem could provide more safe and proper control schedules.

3. Economic Dispatch

ED aims to minimize the operation cost of the target system. It requires predictive information of loads and passive DERs that cannot be controlled. The ED problem subject to the predicted condition tries to optimize the control schedules of controllable DERs. Each DER has to be modeled carefully to enable predictive control.

Target microgrid of this paper is the grid-connected microgrid that contains ESSs as its only controllable DERs. The power quality control is ignored to simplify the problem. Because the ESS could not generate or consume power but only shift it, the ED problem focuses on the optimal scheduling of its ESS operations to minimize the power trading cost with the grid. Unit power trading price is predefined for each hour of the day.

The allowable maximum power for an ESS depends on the amount of power it has been used. It is represented as the time-dependent condition of an ESS named state of charge (SOC). The time-dependent property makes the ED